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**PARAMETRIC INVESTIGATION
OF ENCLOSED KEEPER
DISCHARGE CHARACTERISTICS**

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16. Abstract <p>Volt-ampere discharge characteristics of an enclosed keeper hollow cathode discharge were measured as a function of the mercury flow rate and external circuit impedance. Discharge currents were varied from 0 to 1 ampere and voltages were 7 to 39 volts. Batteries and a vacuum tube control circuit were used to obtain characteristics curves that were independent of power supply impedance. Variation of the neutral flow results in changes in the discharge which interact with the impedance of the external circuit, and under some conditions, give rise to multiple operating points.</p>					
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SUMMARY

In the present investigation the volt-ampere discharge characteristics of an enclosed keeper hollow cathode configuration were measured as a function of the mercury vapor flow rate and external circuit impedance. Discharge currents were varied from 0 to 1 ampere and voltages were 7 to 39 volts, by use of batteries and a vacuum tube control circuit.

Variation in the neutral flow results in a change of the effective impedance in the discharge circuit, where the discharge is considered a complex circuit element. The changes in the effective impedance interact with the impedance of the external circuit to change the volt-ampere discharge characteristics. Under some conditions these changes give rise to multiple operating points, which make the control of cathode-keeper discharge more complex.

INTRODUCTION

For the last several years, research and development work on electron bombardment hollow cathode ion thrusters has been in progress at the Lewis Research Center. The area of thruster cathode development is outlined in a paper by Weigand and Nakanishi. At the present time, the hollow cathode design (ref. 1) seems the most appropriate for thruster applications in that it may be ground-tested before flight and exhibits long lifetime.

The use of this type cathode, however, makes the thruster operating conditions more complex and, therefore, requires a more complex power control system. In past development programs, with large thrusters, a ring keeper was used (refs. 2 to 5) and operational characteristics were determined to permit confident operation of the cathode-keeper system, even though a detailed understanding of the discharge mechanism has not been achieved.

In a following 5-centimeter thruster program (ref. 6), which used an enclosed keeper configuration, the previous work pertaining to the ring keeper was of limited use. To establish a high level of confidence for the enclosed keeper requires an understanding of the enclosed keeper characteristics and their interaction with the power processing unit.

To determine the interactions between the hollow cathode - enclosed keeper discharge and its external circuit is the subject of this investigation. Several sets of characteristic volt-ampere curves were obtained under different flow conditions and with different values of inductance in the external circuit. Such data are necessary for the design of an optimum thruster power source and controller.

APPARATUS AND PROCEDURE

The test facility in which the experiments were conducted consisted of a 45-centimeter-diameter bell jar with a 15-centimeter liquid-nitrogen-trapped oil diffusion

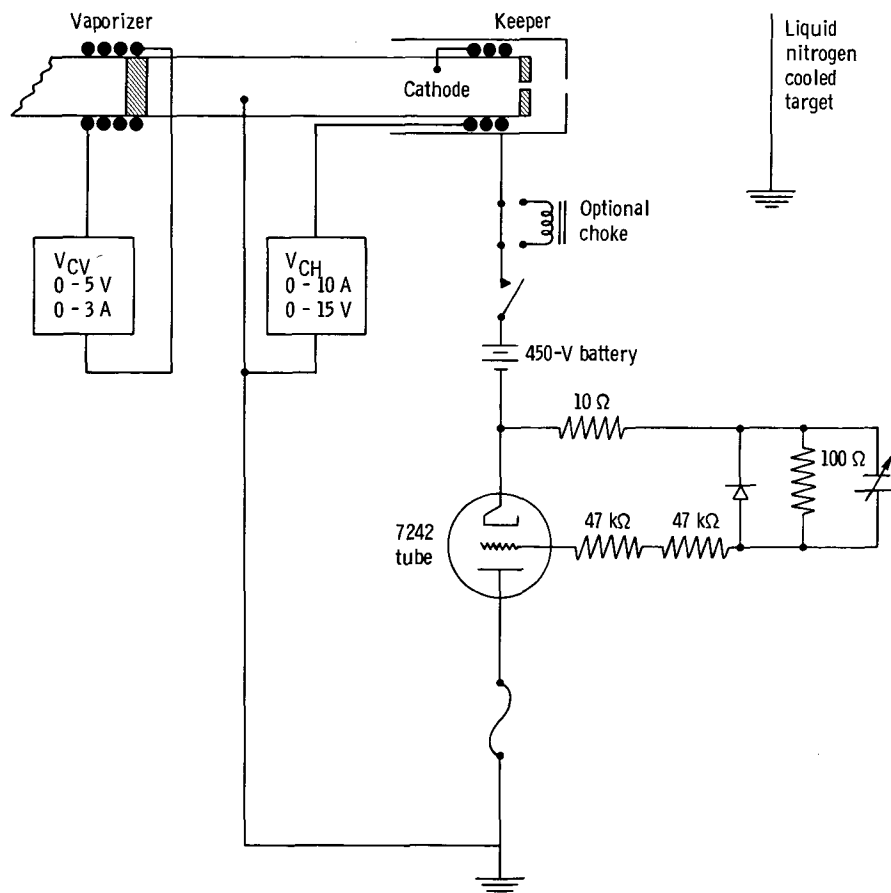


Figure 1. - Experiment system.

pump backed by a 2.8×10^4 cubic centimeter per minute mechanical pump, giving a base pressure in the bell jar of approximately 5×10^{-7} torr and an operating pressure of approximately 6×10^{-6} torr. During cathode operation a liquid nitrogen target is used to condense the mercury from the cathode discharge. Electrical power is supplied to the discharge by ten 45-volt batteries. A type 7242 electron tube in the keeper circuit provides control (as shown in fig. 1) without adding extra inductance associated with wire-wound resistors. Impedance of the external circuit was varied by the addition of a 32-millihenry or 10-millihenry iron core choke, representative of the type found in many laboratory power supplies. The impedance of these chokes were measured, using an impedance bridge at 1 kilohertz and was found to be 26.8 millihenry and 12.6 millihenry, respectively. The experiments were conducted without an anode in the discharge circuit since it was felt an anode might perturb the cathode-keeper discharge characteristics. Twenty watts of power were continuously applied to the tip heater. The cathode configuration used in this investigation is the enclosed keeper type of reference 1 (see fig. 2). Data were taken using a scanner and a digital voltmeter system with a punched paper tape output permitting rapid data taking of several parameters at each operating point.

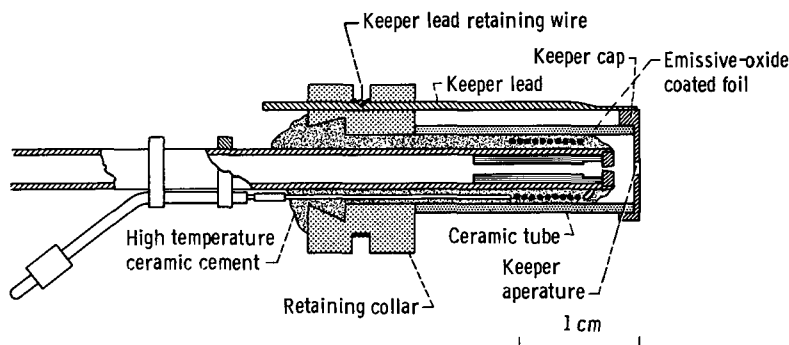


Figure 2. - Enclosed hollow cathode configuration.

RESULTS AND DISCUSSION

Characteristic Volt-Ampere Curves

A typical static volt-ampere characteristics curve, obtained by varying a resistance that is in series with a battery and the discharge is shown in figure 3. Transition points between the different types of discharge are denoted by the numbers 1, 2, and 3, where the region 0 to 1 is the Townsend or dark discharge, from 1 to 2 the glow discharge, from 2 to 3 the abnormal glow, and from 3 an arc discharge. The type of discharge that results upon electrical breakdown depends on the type of gas, the gas pressure, the gap geometry, the nature of applied voltage, and the constants of the external circuit.

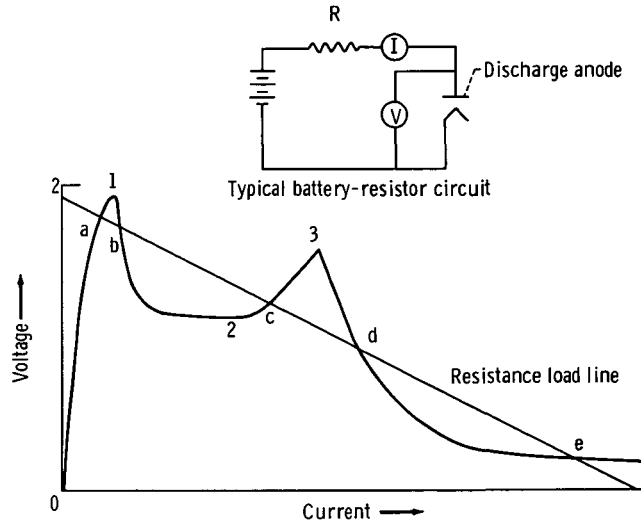


Figure 3. - Static discharge characteristics for typical glow-arc discharge. Numbers denote transition points between different types of discharge; letters denote load line intersects.

The stability of the discharge may be estimated by applying Kaufmann's criterion (ref. 7) as given in equation (1) for given external circuit conditions of pure resistance and direct-current (dc) potential.

$$\frac{dV}{dI} + R > 0 \quad (1)$$

where dV/dI is the slope of the discharge characteristic at the point of intersection with resistive load line.

In figure 3 the load line intersects the volt-ampere characteristic curve at points a, b, c, d, and e. Referring to equation (1), only points a, c, and e would be stable operating points for the discharge. If the discharge is started by bringing the electrodes into contact, an arc type will occur at point e. However, if the discharge is started by slowly increasing the voltage, it will stabilize at point a. With the discharge at point a, further increase in voltage must take place before the discharge current will increase past the first transition point (1), to the stable operating point c.

Power Supply Interactions

Comparing the idealized curve of figure 3 with a characteristic curve taken with a hollow cathode enclosed keeper configuration (fig. 4) shows that the experimental curve is similar to the idealized curve. The volt-ampere curve of figure 4 was obtained with

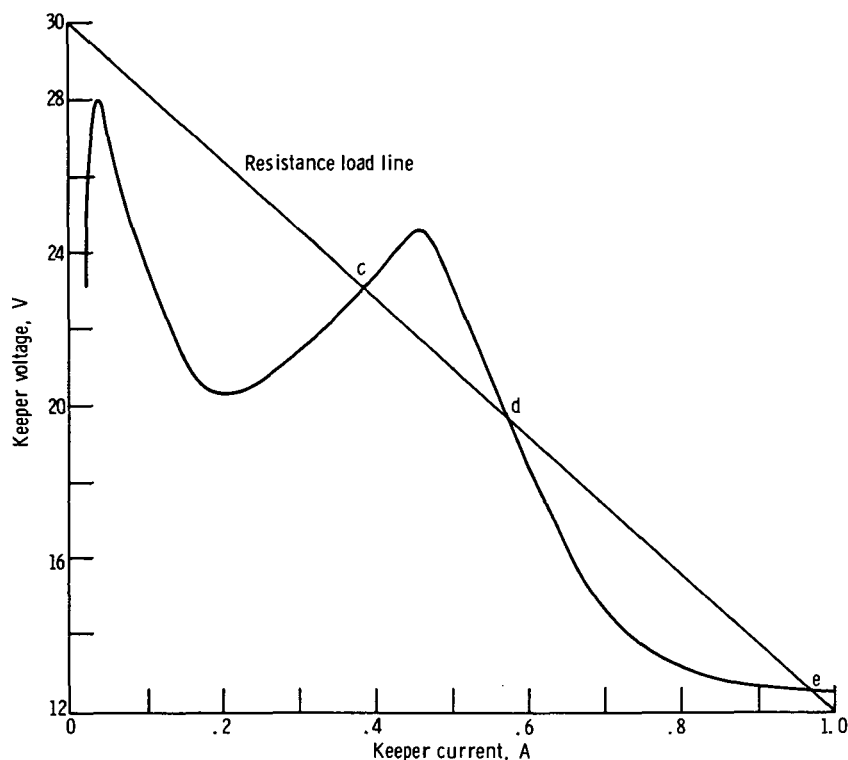


Figure 4. - Keeper current as function of keeper voltage at 45-milliampere equivalent mercury flow rate. Curve obtained with inductive resistor-battery circuit. Load line, is 30-volt, 1 ampere power supply of reference 6. The letters i, d, and e denote load line intersects.

wire wound resistors of unknown inductance in the external circuit. This external inductance may interact with the discharge (ref. 7). The load line shown in the figure was the keeper power supply used in a 5-centimeter thruster test program (ref. 6) and had a finite inductance with a 30-volt limit at a 1-ampere capability. Point c in figure 4 is a point of stable operation, and the discharge current is limited to a maximum value of 0.375 ampere. To increase the current above the 0.375-ampere value would require a change in the discharge parameters such as power to the cathode tip heater or an increase in neutral flow for the present power supply. In conjunction with the present 30-volt, 1-ampere keeper power supply, an igniter power supply capability of 400 volts and 100 milliamperes is used to help initiate the discharge. There are operating conditions, for a given external circuit, where the voltage of the first transition point (point 1) is greater than the 30 volts of the keeper supply, under such conditions the discharge could not be started without an igniter supply. Examples of such a situation are given in table I for the 12.6-millihenry curve of figure 6 and the zero-millihenry curve of figure 7. The voltages of the first transition point are 31.4 and 39.2 volts, respectively, with maximum currents of 0.23 and 0.04 milliamperes. However, should the first transition point be above 30 volts and 100 milliamperes, it would not be possible to further increase the discharge current with the keeper-igniter power supply system of reference 6.

TABLE I. - DISCHARGE TRANSITION POINTS ON CHARACTERISTIC

DISCHARGE CURVES

Figure number	Impedance at 1 kHz, mH	Initial breakdown point		Glow-arc transition point		Equivalent mercury flow rate, mA	Inductance mH
		Voltage, V, V	Current, I, mA	Voltage, V, V	Current, I, mA		
6	0	17.6	0.18	11.65	252	13.7	--
	12.6	31.4	.23	11.2	240	13.7	10
	26.75	12.3	.12	12.4	290	13.7	32
7	0	39.2	0.04	20.0	24	24.7	--
	12.6	13.3	.17	23.3	5.0	24.7	10
	26.75	13.8	.22	21.5	17.0	24.7	32
8	0	15.0	0.17	14.5	48.0	199	--
	12.6	14.6	.24	13.5	82.0	199	10
	26.75	16.7	.11	13.3	60.0	199	32

Experimental Discharge Characteristic Curve Data

In determining the volt-ampere characteristics in figures 5 to 7, the battery power system of figure 1 was used, and each curve was generated from approximately 150 data points that were taken using the digital data system. Three different configurations of the external circuit were used by the addition of iron core chokes in the circuit to vary the inductance. For each circuit configuration, data were obtained for three different flow conditions at a constant cathode tip heater power.

The volt-ampere characteristic curves presented are interpreted, as are those of a glow-arc discharge, but modified by thermionic emission from the heated cathode. The effect of the thermionic emission would presumably shift the first transition point (1) to a lower value of discharge characteristic voltage. Voltage and current values at which breakdown occurs (point (1) in fig. 3) are given in table I. From the volt-ampere curves (figs. 5 to 7), it may be seen that the characteristics do change as a function of both external circuit conditions and neutral flow, with the neutral flow being the primary parameter. With the 26.8-millihenry choke in the circuit there seems to be additional structure in the characteristic curve for both the 24.7- and 199.0-milliamper mercury flow cases (figs. 6(c) and 7(c)). The shifts in the characteristic curves as a function of the neutral flow, the external circuit parameters, or the effect of the emissive oxide-coated foil could account for some of the unpredictable starting encountered with the enclosed keeper - hollow cathode configuration. Without more complete data as to the neutral

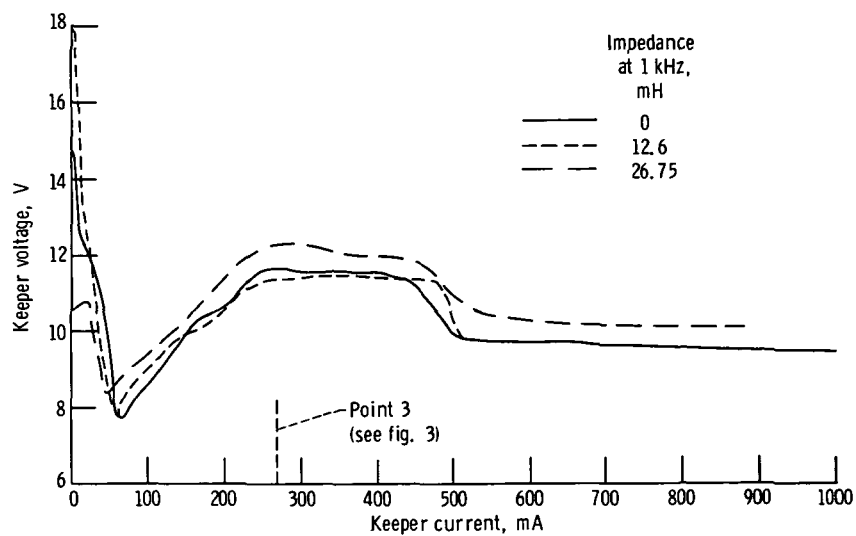


Figure 5. - Keeper voltage as function of keeper current with vacuum tube controlled battery supply. Equivalent mercury flow rate, 13.7 milliamperes.

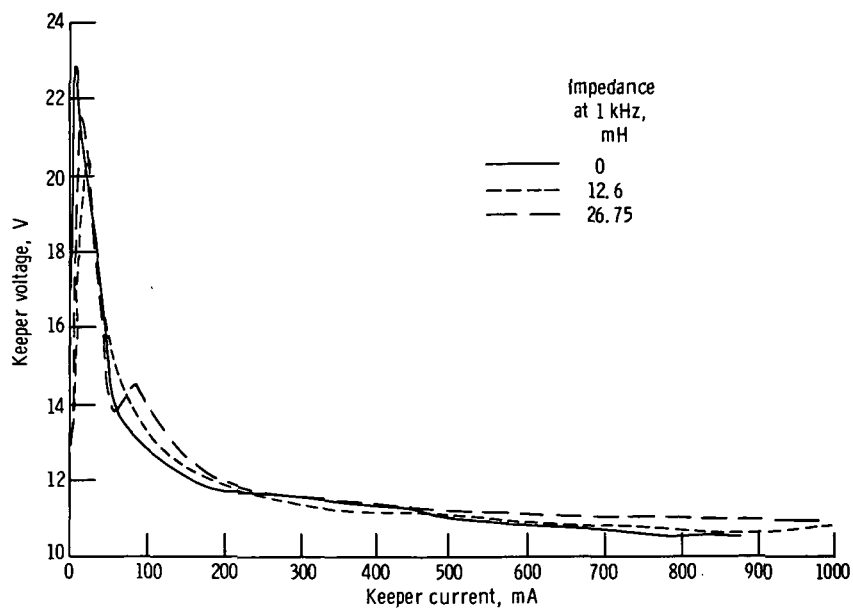


Figure 6. - Keeper voltage as function of keeper current with vacuum tube controlled battery supply. Equivalent mercury flow rate, 24.7 milliamperes.

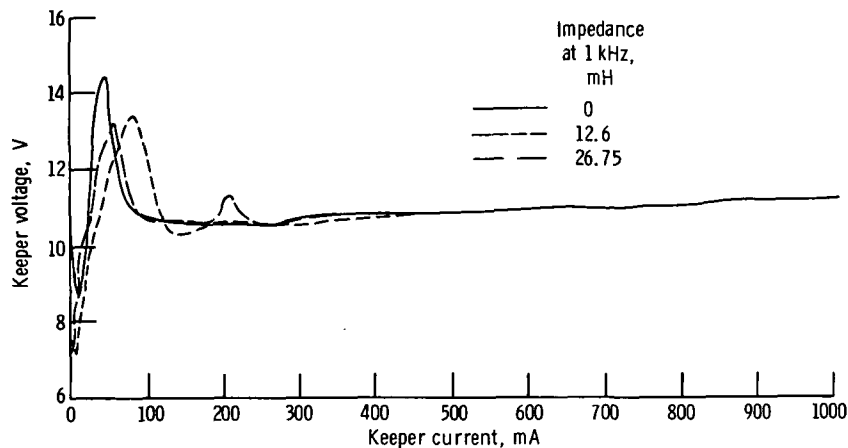


Figure 7. - Keeper voltage as function of keeper current with vacuum tube controlled battery supply. Equivalent mercury flow rate, 199 milliamperes.

vapor composition, pressure, and electrical field in the discharge region, it is a matter of conjecture as to the mechanisms that produce the variation in the characteristics.

CONCLUDING REMARKS

Although there is considerably more research needed in this area, it may be concluded from this investigation that to obtain meaningful data on the discharge characteristics of a cathode-keeper configuration, it is necessary to use a battery power source and control circuit. Further, it was concluded that the variation in neutral flow results in a change of the effective impedance within the discharge circuit. This effective impedance interacts, especially at higher flows with the impedance of the external circuit to produce changes in the volt-ampere discharge characteristics and, in some cases, in the multiple operating points. Such changes in the characteristic curve could, under the same conditions, prevent the cathode-keeper discharge from being established. From the data presented, it can be seen that the operating characteristics of the enclosed keeper configuration are sensitive to the neutral density in the discharge gap; therefore, slight changes, such as cathode or keeper orifice size, would give somewhat different characteristics than reported here. However, the data reported are typical of this enclosed keeper configuration. The changes in the characteristics as a function of neutral flow and external circuit impedance would indicate that a given cathode and thruster should be tested with

the final power supply to be used to give meaningful characteristics curve over the appropriate neutral flow range.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 16, 1973,
502-04.

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